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Saltcedar Control for Wildlife Habitat Improvement in the Southwestern United States

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*Cover photo: Cottonwoods (*Populus *spp.) were planted to replace saltcedar (*Tamarix chinensis*) along the Colorado River near Cibola National Wildlife Refuge, Arizona.*

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By Theodore A. Kerpez
Norman S. Smith

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Contents

Page
Abstract 1
The Ecology of Saltcedar 1
Saltcedar Problems 3
Methods for Controlling Saltcedar 5
  Mechanical Methods 5
  Root Plowing 5
  Chemical Methods 5
  Inundation 6
  Biological Control 6
  Preventing Reinvasion by Saltcedar 6
Case Studies of Saltcedar Control 7
  Revegetation on the Lower Colorado River 7
  The Bureau of Land Management's Work on the Lower Colorado River 8
  Bosque del Apache National Wildlife Refuge 8
Guidelines for Managing Saltcedar 8
  Assess the Problem 8
  Assess Available Solutions 9
  Implement Control 9
  Evaluate the Results 12
Acknowledgments 12
References 12
Appendix. A Subject Index to Saltcedar Evaluation, Management, and Control Literature 15
  Ecology of Saltcedar 15
  Methods of Control 15
  Wildlife-Saltcedar Interactions 15
  Vegetation Measurement Methods 16
  Wildlife Census Methods 16

Saltcedar Control for Wildlife Habitat Improvement in the Southwestern United States

by

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Abstract

Saltcedar (*Tamarix chinensis*) was introduced into the United States from Eurasia during the late eighteenth century and has spread throughout the southwestern United States. Saltcedar is a facultative phreatophyte, evapotranspiring as much as 11,101 m^3 (9 acre-feet) of water per 0.4 ha (1 acre) per year. Saltcedar communities are much less valuable to wildlife than are native riparian plant communities. A manager should assess the saltcedar problem and possible solutions before starting control, and should subsequently evaluate the results. For control, saltcedar must be killed by root plowing, herbicide application, or inundation, and prevented from reinvading. The root plow must cut below the root crown or the saltcedar will resprout vigorously. Presently, two herbicides—2,4-D and dicamba—are registered for use specifically on saltcedar. Saltcedar must be inundated for at least 70 days and possibly as long as 28 months to kill it. Saltcedar can be prevented from reinvading by continuous inundation or by revegetation with native plants. Water 15 cm deep will exclude saltcedar. The selection of species to be planted when revegetating is determined by the soil and groundwater salinity, soil texture, and water table depth. Plantings should be arranged for maximum wildlife benefit. Three case studies show that saltcedar can be controlled successfully.

The Ecology of Saltcedar

Saltcedar, of the Tamaricaceae family, is a large shrub or small tree with slender branches that are covered, when young, by small, scalelike leaves. The small, white or pinkish flowers have four or five sepals and petals, three to five styles, and stamens borne on a fleshy, lobed, hypogynous disk. The flowers produce many three- to five-valved capsule fruits usually having a tuft of hair on the end (Kearney and Peebles 1964). The saltcedar that causes a nuisance in the Southwest is generally referred to in the literature as either *Tamarix chinensis* or *T. pentandra*. The synonomy results from differing recent opinions about the taxonomic status.

Saltcedar was introduced into the United States from Eurasia during the late eighteenth century (Robinson 1958). When first introduced, it was cultivated and sold as an ornamental plant. By the beginning of the twentieth century, however, saltcedar had escaped from cultivation and was naturalized in several southwestern stream valleys (Robinson 1965). Since then, saltcedar has spread rapidly throughout the southwestern United States.

Phreatophytes are plants that depend on groundwater for their water supply. Saltcedar, however, sometimes grows where no groundwater is accessible. It is thus classified as a facultative rather than obligate phreatophyte; that is, one that does not necessarily depend on available groundwater (Turner 1974). A dense stand of saltcedar will grow only where the water table is between 1.5 and 6 m from the surface. If the water table is less than 1.5 m from the surface, the plants branch profusely below the surface and do not form a dense stand (Campbell and Dick-Peddie 1964). When the water table is deeper than 6 m, saltcedar may form an open shrubland with 4.5 to 6 m between individual plants; these survive on rainfall and floodwater (Horton and Campbell 1974).

Saltcedar probably uses more groundwater than native phreatophytes. Robinson (1965) estimated that a tall, dense stand of saltcedar in a dry, hot climate uses more than 11,101 m^3 (9 acre-feet) of water annually per 0.4 ha (1 acre) of saltcedar. Van Hylckama (1974; 1980) measured the maximum annual water used by saltcedar and found that a surface area of 81 m^2 in an evapotranspirometer used 2.52 m^3. This is equivalent to 12,586 m^3 of water annually per 0.4 ha.

From April to October, saltcedar produces large quantities of seeds that are disseminated by wind or water and remain viable for several weeks. The seeds will germinate on saturated soils or while afloat. Once wetted, fresh seeds usually germinate within 24 h (Horton et al. 1960).

Saltcedar seedlings grow slowly and require saturated soils throughout the first 2 to 4 weeks of growth. During this time they will not survive more than 1 day without moist soil. Seedlings can survive submergence for several weeks but are uprooted by even a weak current. Slowly receding water levels along river or reservoir banks create optimim seed beds, but permanent survival requires several months without subsequent flooding (Horton et al. 1960).

Mature plants are tolerant of heat, cold, drought, flood, and high concentrations of dissolved solids (Everitt 1980). By dropping its leaves and halting growth, saltcedar can withstand lengthy droughts (Horton and Campbell 1974). Mature saltcedar can survive complete submergence for as long as 70 days (Warren and Turner 1975). Under saline conditions, saltcedar absorbs dissolved solids and exudes excess salts through glands in its leaves (Decker 1961). These salts are eventually deposited on the soil surface under the plant, sometimes forming a hard crust (McQueen and Miller 1972).

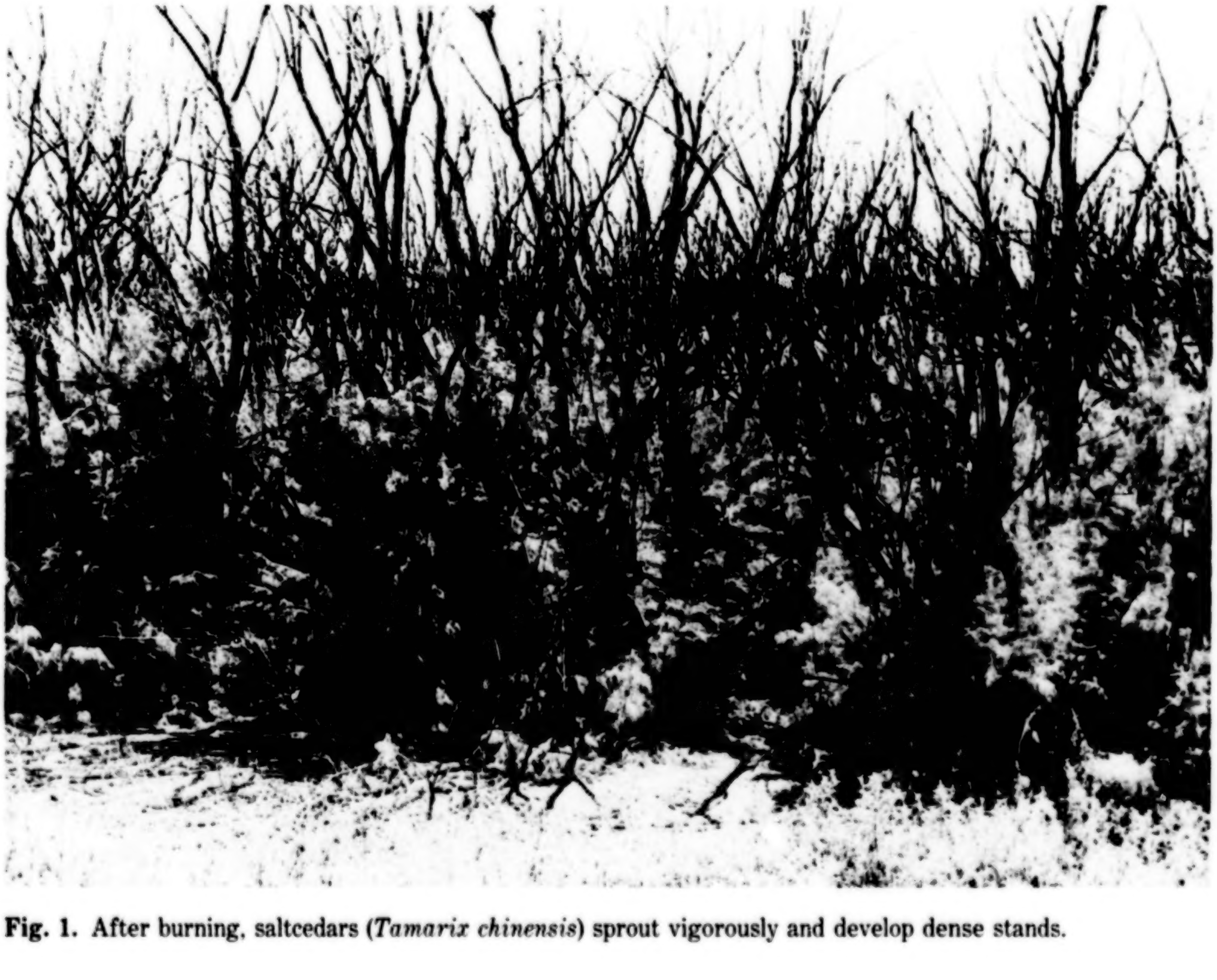

Fig. 1. After burning, saltcedars (*Tamarix chinensis*) sprout vigorously and develop dense stands.

In the absence of frequent flooding, saltcedar communities accumulate litter rapidly and burn every 16 to 20 years. Fires prevent most saltcedar stands from either reaching maturity or persisting as mature communities (Ohmart and Anderson 1978). Saltcedar is not killed by fire and grows back vigorously (Fig. 1). Native riparian vegetation, which is not adapted to fire, is usually replaced by saltcedar after a burn (Horton 1977; Fig. 2).

If saltcedar is cut at or above ground level, the root crown will sprout vigorously. Severed stems and shoots readily root in moist soil and produce new plants, but once dry, they rapidly lose this ability. Adventitious roots sprout from submerged or buried saltcedar stems, and buried branches may also reproduce vegetatively (Merkel and Hopkins 1957). Roots and pieces of roots will not sprout or develop into new plants (Horton 1960*a*).

The rapid spread of saltcedar in the United States is probably related to reservoir construction and the alteration of natural river flows, and to the establishment of suitable seed beds (Everitt 1980; Fig. 3). Larner et al. (1974) found a close correlation between reservoir construction and the increase in area of saltcedar downstream from these reservoirs. Changes in the timing of the annual peak flood of some rivers may also have contributed to its success (Everitt 1980). An area dominated by saltcedar will remain so unless altered by a natural disaster or human intervention (Horton 1977).

Saltcedar Problems

Controlling evapotranspiration by saltcedar in arid areas has been a primary management concern. Most research and eradication efforts have been aimed at decreasing the amount of water used by saltcedar and therefore increasing the amount available for human use. Saltcedar has been blamed for increasing flooding by forming a partial barrier to floodflow, which can cause floodwater to disperse and inundate areas that otherwise would not be flooded (Robinson 1965). Saltcedar has also been

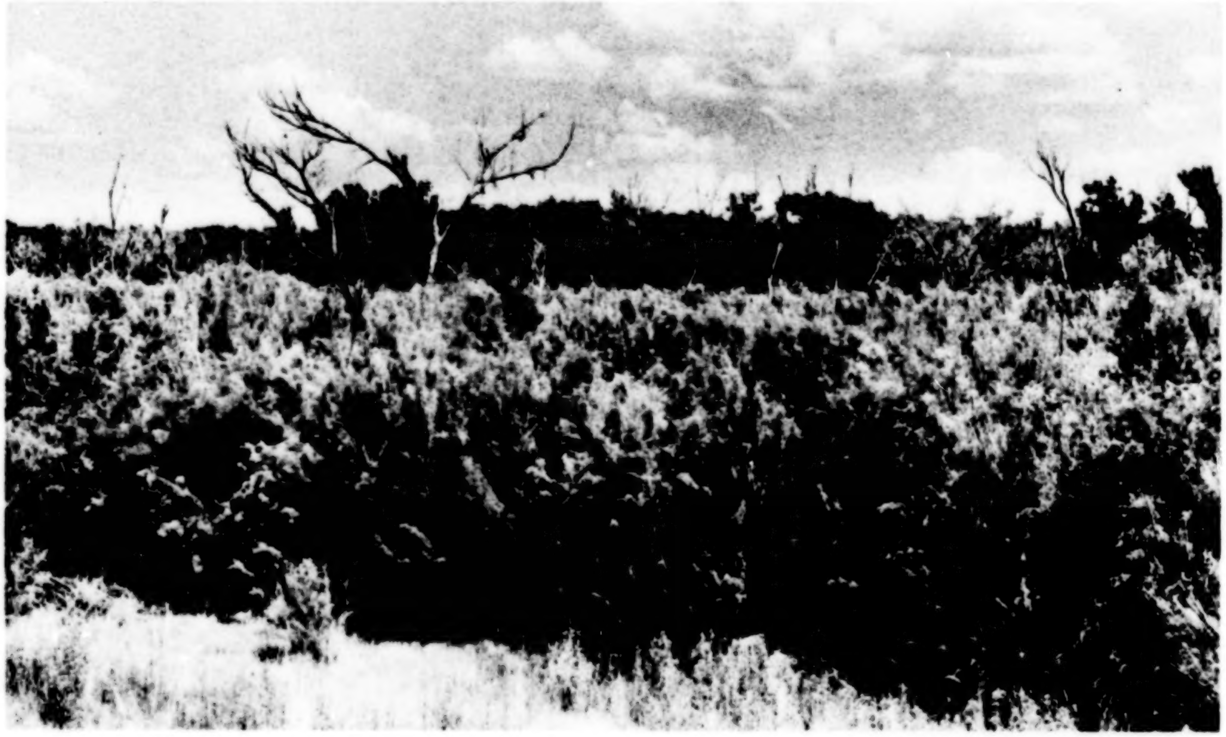

Fig. 2. Native vegetation such as cottonwood (*Populus* spp.) is commonly killed by fire (note dead stems) and is often replaced by saltcedar (*Tamarix chinensis*).

blamed for reducing channel widths by decreasing water-flow velocities and thereby increasing the deposition of sediment (Grozier 1965). However, Everitt (1980) states that there is no convincing evidence supporting either of these charges.

The study of the effects of saltcedar on wildlife is relatively recent. Anderson et al. (1977) compared avian use of saltcedar communities with use of native riparian communities that contained Fremont cottonwood (*Populus fremontii*), black willow (*Salix nigra*), honey mesquite (*Prosopis glandulosa*), and screwbean mesquite (*P. pubescens*) along the lower Colorado River. Saltcedar had lower value to birds than any of the native tree communities based on total bird density, the number of species present, and bird species diversity. When saltcedar was cleared from a 20-ha area along the lower Colorado River and replaced with native vegetation, avian density and diversity increased significantly along with an increase in rodent density (Anderson and Ohmart 1982*b*, 1985). Engel-Wilson and Ohmart (1978) compared saltcedar communities and cottonwood–willow communities along the lower Rio Grande and found that cottonwood–willow communities supported greater densities of birds and higher bird species diversities than did saltcedar communities.

Frugivores and insectivores, abundant in native riparian vegetation, almost completely avoid saltcedar. Frugivores probably do not use saltcedar because desert mistletoe (*Phoradendron californicum*), an important food, does not grow on saltcedar (Cohan et al. 1978; Anderson and Ohmart 1984). Cohan et al. (1978) found a significantly smaller biomass of insects during most seasons in saltcedar communities than in native riparian communities. Carothers et al. (1976) reported that insect production fluctuates dramatically on saltcedar compared with native plants. These findings may explain why insectivores seldom use saltcedar. The

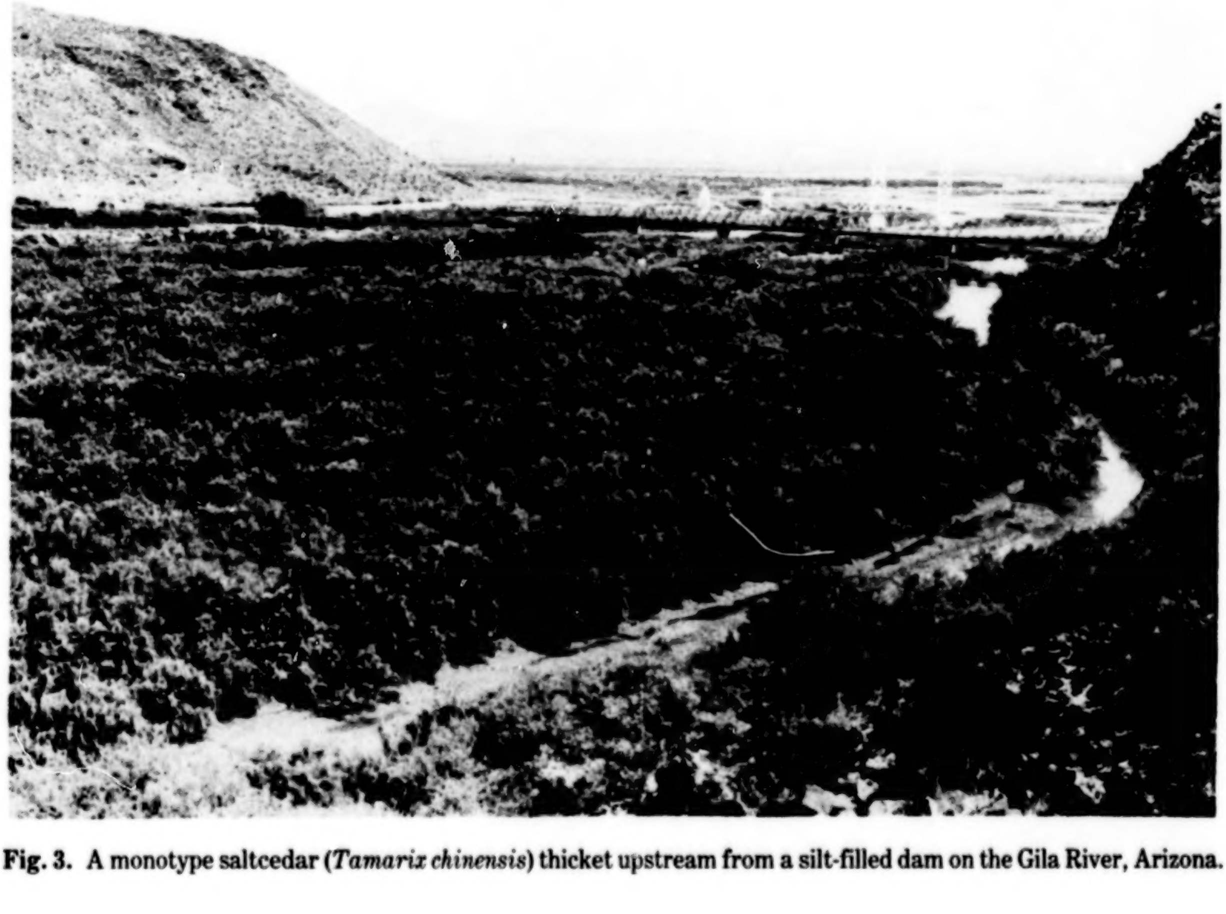

Fig. 3. A monotype saltcedar (*Tamarix chinensis*) thicket upstream from a silt-filled dam on the Gila River, Arizona.

sticky substance exuded by saltcedar leaves also may damage bird plumages (Cohan et al. 1978).

Saltcedar provides nesting sites for white-winged doves (*Zenaida asiatica*) and mourning doves (*Z. macroura*). These doves historically nested in mesquite bosques, most of which have since been cleared (Arnold 1943; Wigal 1973). Saltcedar provides less food for doves than does mesquite. Consequently, doves nesting in saltcedar obtain most of their food from agricultural fields nearby (Horton and Campbell 1974). Saltcedar is also valuable to bees. Saltcedar thickets are a refuge for European honeybees (*Apis mellifera*) when insecticides are applied to nearby croplands (Horton and Campbell 1974). Saltcedar also provides an early source of pollen for overwintering bees (Affleck 1975).

With the possible exceptions of doves and bees, saltcedar communities are clearly much less valuable to wildlife than are native riparian plant communities.

Methods for Controlling Saltcedar

Two steps are necessary for controlling saltcedar: It must be killed and removed. Once an area is cleared of saltcedar, reinvasion must be prevented. Methods for removing saltcedar are presented first.

Mechanical Methods

Conventional mowing severs vegetation about 25 cm above ground level, shredding the plants. This technique works best on woody vegetation 5 cm or less in diameter. Pulling a heavy chain between two tractors (chaining) shears trunks near ground level or sometimes uproots entire plants. Chaining works best when tree trunks are 10 to 46 cm in diameter. Bulldozing shears plants near ground level or can uproot whole plants of almost any size. All of these methods have been used (Bureau of Reclamation 1977) but have not permanently eradicated saltcedar because they do not destroy the subsurface root crown. If left in the ground, the root crown will produce vigorous sprouts that can reach a height of 3 m in one season (Gary 1960).

Root Plowing

A root plow shears vegetation below the soil surface. To ensure cutting below the root crown of saltcedar, the root plow must be between 31 and 46 cm below the ground. If the root crown is removed, lower roots will not sprout and form new plants (Horton 1960*b*). The above-ground vegetation can be removed before or during root plowing, and should be piled and burned to prevent resprouting of shoots and stems. Root plowing during hot and dry weather (which promotes rapid drying of severed stems and shoots) will help prevent resprouting of unburned stems or shoots. Long, straight, and overlapping swaths should be root plowed to avoid missing plants.

Properly done, root plowing should be 100% effective. In practice, root plowing has killed more than 90% of the saltcedar present (Horton 1960*b*; Anderson and Ohmart 1979). Presently, it is the most effective method available.

Chemical Methods

Herbicides can be applied on the foliage, to the base of the plant, to the stump of cut plants, or to the root zone (with a modified root plow) (Hollingsworth et al. 1973). Application of herbicides to cut stumps kills more saltcedar than basal applications to live stems (Hughes 1965). Stump treatment may require more effort because the trees must be cut first. However, the initial effort is recovered because removal of the dead trees would probably be necessary after basal application.

Hollingsworth et al. (1973, 1979) modified a root plow for subsurface placement of herbicides. They mounted a spray pipe with five nozzles along the rear edge of a root-plow blade. A metal pipe and flexible hose connected the spray pipe with a sprayer mounted on top of the plow frame. The root plow severed the saltcedar roots and simultaneously applied herbicide to the cut-root zone. This killed as many as 45% more saltcedar plants than did root plowing alone.

Many herbicides have been tested for effectiveness on saltcedar (Frost 1960; Hughes 1965; Hollingsworth 1969, 1977; Hull et al. 1974). Generally, silvex (2,4,5-TP) was found to control saltcedar best (Frost 1960; Robinson 1964; Bureau of Reclamation 1977). Silvex was registered with the Environmental Protection Agency, but is no longer allowed for commercial use in the United States. In 1986, two herbicides—2,4-D and dicamba—were registered for use specifically on saltcedar. There are two formulations of 2,4-D and four of dicamba (Table 1).

Table 1. *Herbicides specifically registered for use on saltcedar.*

Trade name	EPA number	Active ingredient (%)	Herbicide
Visko-Rhap (soluble A-3D herbicide)	359-650	61.01	2,4-D
Visko-Rhap (oil-soluble amine A-3D)	359-5135	63.9	2,4-D
Banvel (10G)	876-29	11.8	dicamba
Banvel (5G granule)	876-103	5.9	dicamba
Banvel (XP pellets)	876-178	11.8	dicamba
Banvel (XG—industrial granule herbicide)	876-442	12.5	dicamba

Dicamba granules and pellets are applied as a soil treatment to pastures, rangelands, and noncropland (fence rows, rights-of-way, roadsides, wastelands, and similar areas) but not in a manner that will allow the herbicide into irrigation ditches or water for domestic use. Hollingsworth et al. (1979) applied a water-soluble dicamba with a modified root plow in an experimental plot in Kansas. Five years after application they observed a 90% kill of saltcedar. According to Kearney et al. (1969), dicamba persists in soil for about 2 months; however, Harger (1976) found that 16% of the dicamba applied under field conditions remained in the top 7.5 cm after 16 weeks. Yu et al. (1975) reported that, when ^{14}C dicamba was added to a model ecosystem, radioactivity was found throughout the system. This implies that dicamba possibly persists longer than 2 months and is not restricted to the top 7.5 cm of soil.

Pimental (1971) reported the lethal concentration or dosage of dicamba on different animals (Table 2).

The oil-soluble Visko-Rhap 2,4-D may be applied as a foliar spray to control saltcedar in areas similar to those for which dicamba is used. Foliar sprays usually defoliate and often kill the above-ground parts of saltcedar, but the plant usually survives by resprouting if the root system is intact (Hollingsworth et al. 1979).

When saltcedar is killed by herbicides, new plants will reinvade unless native vegetation is reestablished; otherwise, the area has to be retreated. We know of no attempts to revegetate with broad-leaved tree or shrub species after chemical treatment of saltcedar; thus, we are reluctant to recommend herbicide use on wildlife areas until research indicates it will succeed without detriment to wildlife species.

Hansen et al. (1983) provide a guide to proper use of herbicides. Managers should follow all required planning and permitting procedures before using herbicides.

Inundation

Long-term submergence will kill saltcedar. Wiedemann and Cross (1978) found that 99% of saltcedars were killed when inundated for a 28-month period that included the entire first growing season and more than half of the second and third growing seasons. When saltcedars were inundated for 17 months, only 28% were killed. Mechanical manipulation of saltcedar followed by 17 months of inundation killed 77% of the trees. However, Warren and Turner (1975) reported that 70 days of inundation killed all saltcedars. The differences in length of inundation reported as necessary to kill saltcedar may be due to differences in how the authors determined mortality.

Inundation is more effective if preceded by bulldozing or chaining to remove the above-ground portion of saltcedar. But inundation, combined with the cost of bulldozing or chaining, requires more time and may be as expensive as root plowing.

Biological Control

Watts et al. (1977) examined the possibility of biological control and found no potential agents among our native insects or microorganisms. Natural control agents in saltcedar's native habitat have not been identified but should be sought.

Preventing Reinvasion by Saltcedar

Once an area is cleared of saltcedar, a reinvasion must be prevented. Two known methods of prevention are continuous inundation and revegetation with native plants.

If an area is continuously inundated, saltcedar seedlings cannot survive. The water depth is not important; 15 cm is sufficient. Interruptions of inundation, if necessary, should be made during winter when saltcedar seeds are least likely to germinate.

Table 2. *Lethal concentrations (LC50) or lethal dosages (LD50) of dicamba for tested invertebrates, fish, birds, and mammals (Pimentel 1971).*

Animal	Concentration	Reference
Amphipod *(Gammarus lacustris)*	24 h LC50 10,000 ppb	Sanders, 1969
Amphipod	48 h LC50 5,800 ppb	Federal Water Pollution Control Administration, 1968
Honeybee *(Apis mellifera)*	3.6 μg/bee	Edson and Sanderson, 1965
Coho salmon *(Oncorhynchus kisutch)*	24 h LC50 151 ppm	Bond et al., 1965
Rainbow trout *(Salmo gairdneri)*	48 h LC50 35 ppm	Bohmont, 1967
Bluegill *(Lepomis macrochirus)*	48 h LC50 130 ppm	Bohmont, 1967
Pheasant *(Phasianus colchicus)*	LD50 673 mg/kg (female)	Edson and Sanderson, 1965
Pheasant	LD50 800 mg/kg (male)	Edson and Sanderson, 1965
Rat *(Rattus norvegicus)*	LD50 2,900 mg/kg	Pimentel, 1971

Once established, native plants exclude saltcedar seedlings and are more valuable to wildlife (Anderson and Ohmart 1979, 1982*b*, 1985; Everitt 1980). Fremont cottonwood, black willow, honey mesquite, blue paloverde (*Cercidium floridum*), quailbush (*Atriplex lentiformis*), and inkweed (*Suaeda torreyana*) should be planted in combination where possible. If the soil is too saline for the tree species, quailbush and inkweed only may be planted (Anderson and Ohmart 1982*b*, 1985).

In desert riparian areas the roots of planted trees must gain access to the water table. If rooted seedlings are planted, irrigation is required until their roots reach the water table (Anderson and Ohmart 1979). Long cuttings of trees may also be placed in holes augered to groundwater (Swenson and Mullins 1985). Because the cuttings contact the water table, irrigation is not necessary.

Case Studies of Saltcedar Control

Most past efforts to control saltcedar have been to increase the amount of water available for human use. In the three cases that follow, the primary goal was to increase the value of the area to wildlife. These cases provide examples for managers of refuges and other areas primarily concerned with wildlife and wildlife habitat.

Revegetation on the Lower Colorado River

Anderson and Ohmart (1979, 1982*a*, 1982*b*, 1985, personal communication) cleared and revegetated a 20-ha area on the lower Colorado River near Blythe, California, that was originally dominated by saltcedar. Before clearing, it supported an average of 345 trees per ha. First they bulldozed the aboveground portion of saltcedar into piles that were burned. The area was then root plowed about 30 cm below the surface and leveled. This treatment left no immediate sign of any living saltcedar. Within 7 months there were 59 saltcedar trees per ha; all had regenerated from surviving root crowns. These regenerated plants were chopped off below groundlevel with hand tools.

Fremont cottonwood, black willow, honey mesquite, and blue paloverde seedlings were started in a greenhouse from local stock, and seeds of quailbush and inkweed were collected from local plants. Seedlings were planted in an arrangement designed for maximum wildlife value (Anderson and Ohmart 1982*b*, 1985). This arrangement was based on a previous study of vegetation characteristics that were correlated with avian densities and diversities (Anderson et al. 1978; Anderson and Ohmart 1982*b*, 1985) and was similar to the arrangement we describe later on revegetating for terrestrial species. For each seedling, a hole was augered to the water table. Seedlings were irrigated at least until their roots reached the water table (5 to 12 months).

The survival of trees on this site for as long as 5 years has been high—more than 95% in some instances. The shrubs have also responded well. Five years after revegetation only 10 to 15% of the saltcedar had regenerated (Anderson and Ohmart 1982*a*, personal communication). Avian density, avian diversity, and rodent density increased significantly (Anderson and Ohmart 1982*b*, 1985).

The Bureau of Land Management's Work on the Lower Colorado River

The Bureau of Land Management (BLM) has cleared and revegetated two areas (3.2 ha and 1.6 ha) originally dominated by saltcedar on the lower Colorado River near Yuma, Arizona (J. M. Morgart, personal communication). Because a root plow was not available, they removed the saltcedar with a less efficient front-end loader. For the first year they cleared the saltcedar regrowth every 2 or 3 months with hand tools. After the initial clearing, BLM subjectively placed Fremont cottonwood and black willow seedlings about 12 m apart. These seedlings were started in a greenhouse from local stock. For each seedling, they augered a hole to the water table and irrigated it until the roots reached the water table. After 1 year, most of the trees were 3.5 to 4 m high; BLM concluded that even with no further treatment saltcedar will not reinvade. Their optimism, however, is not shared by all other biologists working with saltcedar (B. W. Anderson and R. D. Ohmart, personal communication).

Bosque del Apache National Wildlife Refuge

The Bosque del Apache National Wildlife Refuge, near Socorro, New Mexico, has mowed and inundated several areas 80 ha to 120 ha that, if left alone, would be dominated by saltcedar (W. W. Hutchinson, personal communication). Refuge workers mow the saltcedar each year during August and September, and then flood the areas from October through April (Fig. 4). Between April and August the saltcedar grows back to a height of about 1.8 m. The process is then repeated. While flooded, the areas provide open water and aquatic vegetation for wintering waterfowl. The success of this refuge practice is affirmed by the thousands of snow geese and sandhill cranes that use these areas, attracting bird watchers and photographers who easily view the birds.

Guidelines for Managing Saltcedar

Assess the Problem

To assess the problem, a manager must determine the distribution, dominance, age structure, and stability of saltcedar communities in the management unit.

Saltcedar distribution can be mapped either on foot or from the air, depending on the amount of area involved. Percent cover of the plant canopy is one measure of dominance and can be determined with the line intercept method (Mueller-Dombois and Ellenberg 1974) on randomly situated transects

Fig. 4. An area initially cleared of large saltcedar (*Tamarix chinensis*) that is thereafter mowed and flooded annually at Bosque del Apache National Wildlife Refuge in New Mexico.

within the distribution of saltcedar. Sample sizes can usually be determined by referring to a statistical methods book. In essence, the number of samples needed depends on variation within saltcedar stands. If all of the stands are old, with continuous closed canopy, there is little need for many samples. However, if there is large variability, more samples are needed. Transect locations should be permanently marked.

To estimate age-class, categories such as seedling, sapling, young trees, and mature trees might be useful. Some combination of height and basal diameter can be developed to assign plants to age-class categories. The key is to be consistent and use the same criteria from sample to sample and from time to time.

General criteria are provided earlier because a single set of criteria would be difficult to develop to address all situations. Management objectives can differ and various amounts or types of saltcedar stands may be acceptable.

Usually the manager knows what types of saltcedar stands contribute as wildlife habitat, but the knowledge will not be quantified. Wildlife species of interest to management objectives should be quantified in the various saltcedar habitats in a repeatable way. Subsequently, when measurements of saltcedar suggest the habitat is changing, the wildlife indices may be compared for changes. Measurements of the saltcedar alone, however, may not always tell the whole story. For example, two stands of mature saltcedar may be similar but the number of doves nesting on each stand may be dissimilar. Large amounts of grain planted nearby may allow more doves to nest than if cotton were planted close to the nesting habitat.

The ability to control fire should also be considered when assessing the extent of the problem. Mature saltcedar stands are more beneficial to wildlife than immature stands but fire usually recurs before a stand matures (Anderson et al. 1977). To our knowledge, no one has eliminated fire from saltcedar stands for long periods, possibly because suppression efforts were inadequate or impractical.

Recommended sources of additional information about ecology of saltcedar, methods of control, wildlife–saltcedar interactions, vegetation measurement, and wildlife census methods are included in the Appendix.

Assess Available Solutions

To control saltcedar, existing plants must be removed or killed and future reinvasions prevented. Presently, root plowing and long-term inundation are the only good removal methods. Root plowing is usually quicker and probably more effective than inundation. In addition, there is some question about how long saltcedar must be submerged before it dies. When root plowing cannot be done and water is available, inundation is the best alternative.

Of the methods available for preventing reinvasion of saltcedar, revegetating with native plants or inundation are probably the best. Each is a good solution depending on the circumstances and the reasons for saltcedar control. When equipment is available and water supplies are abundant, inundation may be best if aquatic habitats are the goal. If the ability to manipulate water levels is lacking or if terrestrial habitats are desired, revegetation is the best solution.

Initial costs of revegetation are high but, once established, native stands require only fire and flood protection. If funds are lacking to revegetate large areas simultaneously, small sections may be revegetated over a longer time. The amount treated may vary yearly with the funds or resources available.

Continuous cultivation may also prevent reinvasion of saltcedar and may be a viable option if crops useful to wildlife can be grown.

Implement Control

We present below procedures and recommendations for implementing control in addition to those already discussed.

Root Plowing

Removing the above-ground portion of saltcedar before, rather than during, root plowing will increase plowing efficiency. When possible, leave native vegetation in place.

Inundation for Removal

Removing the above-ground portion of saltcedar before inundation is preferable. All pieces of saltcedar removed should be piled and burned. If plants are not removed, completely submerge them for at least 70 days. Some data suggest that saltcedar should be inundated for 28 months (Wiedemann and Cross 1978). If this is not possible, test a small area to determine the optimum period for a given area.

Inundation for Preventing Reinvasion

The water depth should be maintained to provide the most benefit for wildlife.

Revegetation for Terrestrial Species

Testing. To a great extent, the soil and groundwater salinity, soil texture, and water table depth determine which species will grow well in an area. Therefore, it is very important to determine these factors before revegetating an area. Soil and groundwater samples should be collected at random locations throughout the area to be revegetated. Five sample points per 0.4 ha will usually characterize the variation within most areas (B. W. Anderson and R. D. Ohmart, personal communication). At each sample point collect a groundwater sample and two soil samples from different depths. If the water table is less than 3 m deep, take soil samples at about 0.6 m and 1.2 m deep. If the water table is more than 3 m deep, take soil samples at about 1.5 m and 2.1 m deep. The soil and groundwater samples should be analyzed for total soluble salt content, expressed in parts per million (ppm). The highest salinity found in the three samples (two different soil depths and groundwater) taken at each sample point is the salinity used when deciding what species can be planted at that location.

Test the soil texture at each sample point and depth used for determining soil salinity. Soil texture can be estimated by rubbing the soil between your thumb and fingers and using a soil texture pyramid, described in most soil textbooks (e. g., Brady 1974).

Planting. B. W. Anderson and R. D. Ohmart (personal communication) provided the following preliminary set of guidelines for planting. Salinity is the most important and well-defined factor for determining which species can be planted. The salinity guidelines presented in Table 3 are general and should be considered a starting point. If the soil has more clay in it than a loam has, or the water table is much deeper than 3 m, the maximum soil salinity recommended for each species should be decreased. We cannot be more specific because of the current lack of available information. The manager may want to try planting small patches of the salt-intolerant species under several combinations of conditions, to better define these guidelines for a particular area.

Table 3. *Species that should be planted according to soil and groundwater salinity (B. W. Anderson and R. D. Ohmart, personal communication).*

Salinity (ppm)	Plant
2,000 or less	Black willow, Fremont cottonwood, honey mesquite, blue paloverde, quailbush, inkweed
2,000–4,000	Fremont cottonwood, honey mesquite, blue paloverde, quailbush, inkweed
4,000–10,000	Honey mesquite, blue paloverde, quailbush, inkweed
10,000 or more	Quailbush, inkweed

B. W. Anderson and R. D. Ohmart (1984, personal communication) have developed a vegetation arrangement for maximum wildlife benefit. To begin, divide the area into 1.6-ha plots. When subdividing the area, keep the plots as uniform in soil salinity as possible (Figs. 5 and 6). Unless soil salinity precludes it, 75% of the plots should be tree plots, with the remaining 25% planted with quailbush or inkweed plots interspersed among the tree plots (Fig. 7). In the plots that are too saline for trees, plant quailbush or inkweed; quailbush plots should predominate. To reduce competition, trees and shrubs should not be planted in the same plot.

The tree plots should contain honey mesquite or blue paloverde, or both, in sites with soil salinity of 4,000–10,000 ppm; between 2,000 and 4,000 ppm Fremont cottonwood can be planted. A combination of Fremont cottonwood and black willow should be

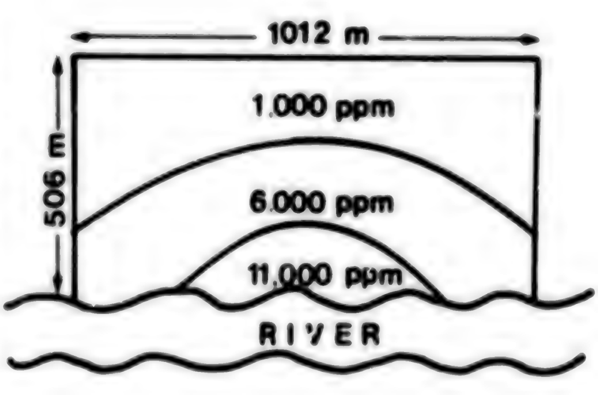

Fig. 5. Soil salinity is of prime concern when revegetating an area cleared of saltcedar (*Tamarix chinensis*). Stylized figure shows decreasing salinity as distance from the river increases.

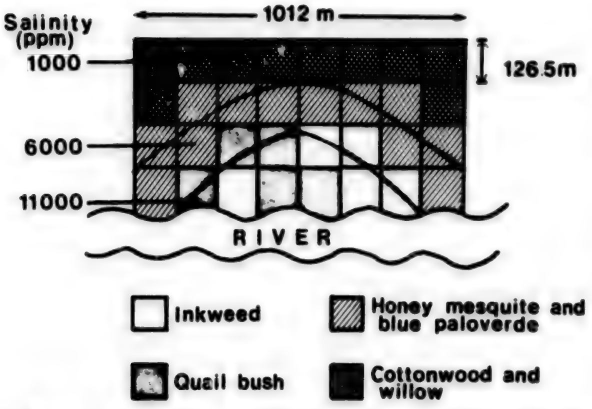

Fig. 6. A hypothetical revegetation arrangement accommodating different soil salinities.

planted if soils contain 2,000 ppm or less. If soil salinity permits, divide the tree plots evenly between those of honey mesquite and blue paloverde and those of Fremont cottonwood and black willow. To avoid competition, do not plant in densities greater than 200–225 trees per ha.

Quailbush and inkweed seeds should be collected from local plants. They can be spread by hand and disked into the soil in winter, immediately before a forecasted rain. Germination will be greater if seeds are soaked in water for 24 h before dissemination in moist soil. The seeds need only a little moisture to germinate; precipitation of 3.6 cm during winter will suffice. However, during the first summer when the shrubs are young and susceptible to drought, occasional irrigation will probably increase survival (B. W. Anderson and R. D. Ohmart, personal communication).

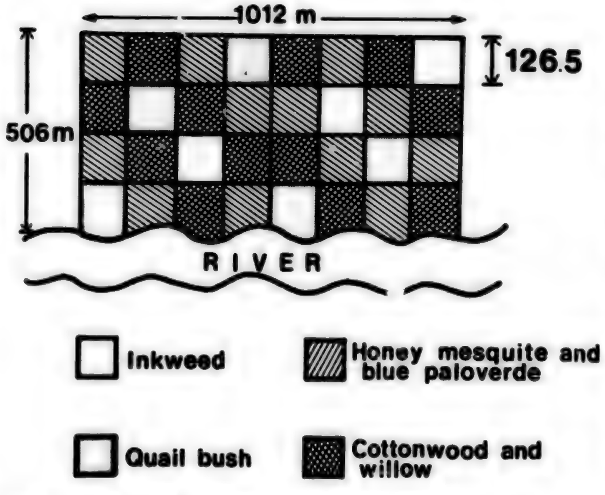

Fig. 7. An ideal revegetation arrangement.

The best time to plant trees is in winter when evaporation is low. Trees planted in rows are easier to monitor and maintain. Even though less pleasing aesthetically, this will not affect the value of the area to wildlife (B. W. Anderson and R. D. Ohmart, personal communication).

Trees can be started by placing cuttings in holes augered to groundwater, or by planting rooted seedlings started in a greenhouse. Because cuttings in contact with groundwater do not require irrigation, the former method is less expensive and easier than planting rooted seedlings. Fremont cottonwood, narrowleaf cottonwood (*Populus angustifolia*), and black willow cuttings have been planted successfully in floodplains over water tables more than 4 m deep (Swenson and Mullins 1985). Nevertheless, to assure planting success it may be better to plant seedlings. In the Colorado River area, survival of cuttings was less than 1% (B. W. Anderson and R. D. Ohmart, personal communication). Preferably, one should test plantings of cuttings on a small section before revegetating a large area. Cuttings should be taken from local plants. The cuttings (poles) may be as large as 7.8 to 10 cm in diameter and preferably 5 cm or greater. After cutting, the side branches should be removed except for those on the top 30 cm and the poles should be put into the ground as soon as possible. If a delay is necessary, the butt ends can be covered with moist soil (C. L. Mullins, personal communication). Mullins also recommended that the first lateral buds should be removed to encourage terminal growth. When planting, assure that the end of the cutting contacts groundwater. Remember that salinity or water quality is also an important consideration when planting cottonwood and black willow poles. Preliminary findings suggest that the poles will not survive in saline waters.

If rooted seedlings are selected, they should be from local sources, started in a greenhouse, and planted when they are 30 to 60 cm tall. Dense soil layers may impede root penetration to the water table. Digging a hole with a backhoe or augering a hole to the water table for each seedling will ensure that its roots can penetrate to groundwater. Seedlings require irrigation until their roots reach either the water table or permanently wet soil (soil to which water has risen by capillary action). The length of time and amount of irrigation required varies with site conditions. Along the Colorado River, usually 4 gallons a day for 3 to 4 months is sufficient. If there are many weeds around the seedlings, or the water table is deep, it may take longer than 3 to 4 months for the roots to reach the water table (B. W. Anderson and R. D. Ohmart, personal communication). To determine when the roots have reached the water table, dig a hole alongside several trees of each species and inspect the depth to which roots have penetrated.

Irrigate with water having the lowest salt concentration available. Irrigating salt-intolerant species with saline water can kill the plants. As a general guideline, do not use water that is more saline than one-third the maximum recommended soil salinity for each species (Table 3; B. W. Anderson and R. D. Ohmart, personal communication).

Anderson and Ohmart (1982*b*, 1985) recommended gasoline- or diesel-operated pumps for irrigating seedlings. These pumps are less expensive than electrical pumps and operating costs are similar. Plastic (PVC) pipe for main irrigation lines must be buried to prevent algae growth that will clog emitters, and to prevent the deterioration of pipe from sun exposure. Lateral irrigation lines of black polyethylene tubing fitted with pressure-compensating emitters will accumulate little algae and can be laid on the surface.

Planted seedlings or cuttings should be protected from livestock, beavers (*Castor canadensis*), small rodents, and rabbits. Hardware cloth placed around individual plants will protect them from rodents and rabbits. Livestock should be excluded by fencing the entire area, and firebreaks should surround the revegetated area. If possible, the area around each tree should be kept weed-free, because weeds compete with trees for water and nutrients, decrease growth rates, and increase tree mortality. Weeds are less troublesome in desert areas with sandy surfaces.

In addition to the preceding recommendations, local experts can be helpful. Local farmers and extension service personnel can often provide useful information on equipment needs, water table depth, and soil structure and chemistry.

Evaluate the Results

By continuing to take measurements made for assessing the problem, one can evaluate the results. By comparing the dominance, age structure, and area occupied by saltcedar before and after control with the response of wildlife, the value of the control effort can be determined.

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Appendix. A Subject Index to Saltcedar Evaluation, Management, and Control Literature

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Saltcedar (*Tamarix chinensis*), an introduced phreatophyte, is spreading throughout the southwestern United States, displacing native plants and habitats valuable to wildlife. For control, saltcedar must be killed and prevented from reinvading. Effective kill of more than 90% has been achieved by root plowing, chemical treatment, or by long-term flooding. Each method, alone or in combination, has specific requirements. Three case histories are described and guidelines for managing saltcedar are given.

Key words: Saltcedar, *Tamarix chinensis*, *T. pentandra*, control, ecology, revegetation, wildlife habitat.

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